Comparative Analysis of Seed Systems in Kenya and Ethiopia: The Role of Intellectual Property in Innovation and Technology Transfer

A Project Paper

Presented to the Faculty of the Graduate School

of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Professional Studies in Agriculture and Life Sciences

Field of International Development

by

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August 2017

ABSTRACT

Widespread access to improved seeds remains a barrier to agricultural development in Sub-Saharan Africa. This paper aims to identify critical policy barriers for technology transfer, access, and adoption in seed systems. A description of seed technology delivery will make evident certain barriers to technology transfer. A comparison between Ethiopia and Kenya will examine national policy in six areas that are critical to technology transfer and innovation. The six policy areas include education, and research and development capacity; regulatory framework; manufacturing capacity; national delivery system; international trade system. There will be a more extensive analysis of the sixth policy area; intellectual property, which this plays a critical role in innovation and technology transfer in seed systems.

BIOGRAPHICAL SKETCH

Adiam Asfaha is a masters student studying international development. His is research at Cornell is in science and technology policy focusing on innovation, technology transfer, and commercialization in agricultural systems. More specifically, strategic and operational strategies in the development, delivery, and adoption of agricultural technologies. He received his undergraduate degrees from Old Dominion University in French and International Relations.

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ACKNOWLEDGMENTS

This work would not have been possible without the support of the faculty and staff of Cornell University. I am especially grateful to Dr. Terry Tucker for guiding me through my research and studies at Cornell. I could not have written this without your input and guidance. I would also like to thank Drs Ed Mabaya, Ndunge Kiiti, Richard Cahoon, and Anatole Krattiger for their advice and expertise. My smooth experience at Cornell was made possible by Denise Percey and the Global Development staff who was always there to help with any academic and professional needs.

I am grateful for the wonderful friends and colleagues I met during my studies. Working and learning with you has been one of the greatest pleasures of my life. I have made lifelong friendship in a very short period of time. I could not have made this far without the support of my family for who I am thankful for. Most importantly, I would like to thank my mother for believing in my personal and professional pursuits.

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CHAPTER 1

Introduction

The “green revolution” marked an important period for agricultural innovation and technology transfer. Great progress was made with access to mechanization, fertilizers, and high-yielding varieties that increased yields, securing higher income for farmers, and sustenance for consumers. Yet many of these innovations have been out of reach for farmers, particularly in Africa. Linear top-down models have dominated technology transfer (TOT) efforts in international development.[1] Agricultural research and TOT has continually produced and pushed blanket solutions with little consideration to what farmers need and can use.[2] A change in the field of international development is afoot, there is a shift from the standard aid model to creating ecosystems for growth. This new strategy represents an effort to foster synergistic linkages that enable innovation as well as improve absorptive capacity of farmers.

Solutions for African farmers is not always technological in nature, but for many, the problems of low productivity, food security, and malnutrition persist[3]; access to improved seed technologies can remediate this. An analysis of bio-technology innovation, development, and delivery will make evident the barriers to innovation and the role that intellectual property plays in seed systems. Additional challenges to technology transfer will also be deliberated.

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[1] (Chambers & Jiggins, 1987)
[2] (Rolling)
[3] (Pretty, Sutherland, Ashby, & Auburn, 2010)

Technology, Innovation, and Technology Transfer

There much overlap with the definitions of invention, technology, and innovation. There is also little delineation between delivering technologies to farmers and delivering products and services to farmers. Public research institutions are sources of inventions and technology in the United States. Technologies are licensed from universities by private companies who develop products and services to consumers. The invention occurs with technological breakthrough in research institution; the innovation is the process extracting value from these technologies by creating products and services around them, making them accessible, and creating value for farmers. Innovation has also been loosely defined, for the purposes of this paper innovations will be defined as a novel technology that adds value to farmers and in the larger context of in seed system, innovation will be geared towards improving access and adoption.

Value derived from an innovation is subjective to the end-user. In the context of small holder African farmers, seeds can be socially and economically valuable. Economic value from improved seeds can be derived from increase biological yield, decreased use of inputs, and even less labor just to name a few. Social value can be derived from the image and reputation of certain crops over others; for example, Ethiopian white teff has higher value over brown teff even though brown teff is more nutritious. Prestige and social standing are not often considered in plant breeding, but these are consideration that farmers make when choosing which technologies to adopt.

The traditional TOT model from public agricultural research institutions to farmers has received much criticism. It evaluates technologies based on farmers adoption; lack of adoption is often blamed on the farmer rather than evaluation of the technology for poor fit. The TOT model also takes a homogenous view of farmers, discounting the environment farmers operate in. Often times, these technology transfer initiatives from agricultural research institutions were led by scientist with very narrow fields of expertise; private sector adaptation, and contributions by non-scientists sector were undervalued. A more comprehensive view of technology transfer will show that the process for both resource rich and resource poor farmers is difficult to achieve but must be sought. When moving to the new paradigm of innovation systems in agriculture, the archaic views of technology and innovation shouldn't be inherited.

Technology can be an improved variety of seeds, a tractor, fertilizer, know-how for planting, and even a method for soil management. These are but a few examples of technologies. The transfer and adoption process of each of these technologies is different from one to the other. Each of these technologies will fail for different reasons in different contexts. In the same light, technology transfer in agricultural systems is not limited to agricultural research institutions interacting directly with farmers. Technology transfer and adoption occurs across public, private, and informal sectors. It can occur through trade, when a small holder farmer purchases a seed. Internationally, it can take place through foreign direct investments; when a private company company build sets up a flower farm in Ethiopia and local farmer learn the know-how to build greenhouses. The proliferation of cell phones in sub-Saharan African is another example of technology transfer. When discussing technology, and technology transfer; context must be considered. The failures and successes of technology transfer must be localized to technologies, actors, recipients, and modes of transfer.

Criticisms of top-down technology transfer are well founded but they don't delve into the actual causes of the failure. The nature of the intervention must also be considered. The traditional technology transfer is criticized for its 'silver bullet' approach of technology application to development. There is black a white view of technology when it clearly is not the case; technology is not the solution for development; technology is also not good, bad, or neutral.[4] Promotion of technology transfer efforts are often not made with agreement and input from the recipients. Social considerations are often not contextualized culturally and geographically, technology has social implication both positive and negative ones.[5] Technology in the context of agricultural development can be an extension of labor that farmers use to increase productivity, or it can be something that reduces harvest loss and environmental degradation.

Technology development and transfer are initiated take place in two different ways. The supply-push model and the demand-pull model. The supply-push model is when technologies are developed and deployed without an expressed need for them, a product that is pushed on to the market. The demand-pull model is one where technologies are developed to solve specific needs of users, a product that is demand driven from consumers. There has been more success with the supply push model of technology development when targeting a uniform body of farmers, but for complex diverse and risk-prone farmers, a more tailored demand-pull model is needed. Both models can fail in supportive socio-economic conditions, both models can also succeed in the most unlikely of places. The successful development of cell phones is an example of the latter. When Nokia developed the first mass market cell phones, they carried out diligent research in emerging markets. Ethnographic observational studies were conducted in the most rural areas of Africa, South East Asia, and South America. The research team followed consumers and even went into people's bags to find out what they carried; this was the reason behind which phonebook and calendars were among the first applications developed in cell phones. Nokia did

[4] (Mims, 2017)
[5] Ibid

not ask their consumers if they wanted cell phones or what applications it should come with, they identified a need and met it.

The success of cell phone was in part due to the tremendous amount of work that went into product development but also the complimentary assets and networks externalities needed to support the adoption of this particular technology. Complimentary assets are factors that enable technologies, in the case of cell phones, they can be electricity, a mobile service network, and associated infrastructure needs. Network externalities can be direct and indirect; this phenomenon are the positive effects that come from a large number of users of a certain technology. Mobile phones are useful when other people use mobile phones, the larger the network of mobile phone users the more useful they become to users. Complimentary assets and network externalities can render technologies inapt; large machinery in sub-Saharan Africa are an example of this. There are numerous development projects that have attempted to deliver technologies in communities that don't have the necessary complimentary assets; in the case of tractors, it could be the availability of fuel, the know-how to repair or operate them efficiently, or access to parts. With low rates of adoption there often aren't enough dealers that could supply spare parts, or other network externalities to sustain and grow their adoption. Successful technology diffusion can be impeded by these two factors; even in the most developed markets very few technologies fail to reach mass market for this reason.

In the case of seeds, complimentary assets can be a fertilizer, pesticides, machinery used to plant them; anything that can enable the function of a technology to its full potential. Complimentary assets for seeds must also meet additional requirements that many other types of technologies do not. Seeds must be adapted to various agro-ecological condition, they have to be resistant to abiotic stressors, and localized to different soil conditions. For this reason, seeds and many other technologies have seen more widespread adoption among large groups of homogeneous farmer and less so with farmers in heterogeneous conditions.

A multi-disciplinary approach found in public research institution in not sufficient to support innovation targeting this type of consumer because it does not substitute the capacity for down-stream product development found in the private sector. In this context and many others, agricultural research institutions and scientist have not been the innovators but the inventors. Invention and technology deployment should not be confused with delivering innovative products and services. Simply deploying seeds to farmers is insufficient without localizing and breeding varieties to meet farmer's needs and conditions. When promoting innovation and technology transfer, in the context of the African seed sector, consideration for the enabling environments are usually absent.

CHAPTER 2

Bio-technology Development and Delivery

Agriculture is not often associated with high technology – defined as advanced technology. Low technology, that is less advanced or relatively unsophisticated technologies, are what people think when crop and soil sciences come to mind. In the information age, technology has become synonymous with information technologies such as hardware and software. Even with recent advances in biotechnology, agriculture remains the most underrated sector in technology.[6] Seeds carry the characteristics of both high technology and low technology. Sourcing germplasm, phenotyping, genetic-modification, and gene-editing are highly complex and sophisticated processes that carry elements of high technology. Their use on the other hand carry the characteristics of low technology; seeds are simple enough that they do not require literacy, and in most cases, they are easy to use. These characteristics make seeds a low-hanging fruit in agricultural development, but it also makes them prone to insufficient down-stream development. In some instances, seeds can simply be developed in public research institutions and be deployed directly to farmers. This has worked mostly for resources rich farmers in homogeneous agro-ecological conditions, this model has not worked for resource poor farmers in that are complex, risk-prone and diverse.[7] These farmers require a more iterative down-stream development process that localized technologies to meet their needs. The private sector is unlikely to target these types of consumers due to limited margins that can be extracted from low-income farmers.

[6] (French, 2017)
[7] (Scoones & Thompson, 2009)

Seeds have been among the most successful technologies in terms reaching small-holder farmers. Their affordability and ease-of-use have allowed them to penetrate agricultural systems easily relative to other technologies. Technology transfer from high-income to low-income countries takes place across sectors and industries. There is potential for rapid adoption rates of sophisticated products even with low-income consumers. The success of mobile phones in Africa is a good example of such technology diffusion. This kind of technology development and delivery does not occur in a vacuum, seeds are not an exception. Seeds are developed from multiple inventions, backed by international investors, national research institutions, the private sector, and financial institutions.[8]

Seed systems in Africa are highly fragmented with research, development, production, processing, distribution, and farmer utilization involving numerous players, sometimes with conflicting interests.[9] There has been nominal return on investment made in improving seed systems in sub-Saharan Africa. Figure 1 displays how seed systems are structured in Africa. There is high fragmentation with various types of institutions at every stage of seed development and delivery. The image below describes the formal seed sector, which is complimented by, the much larger, informal seed sector.

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[8] (Vijayaraghavan, 2017)

[9] (Alliance for a Green Revolution in Africa, 2013)

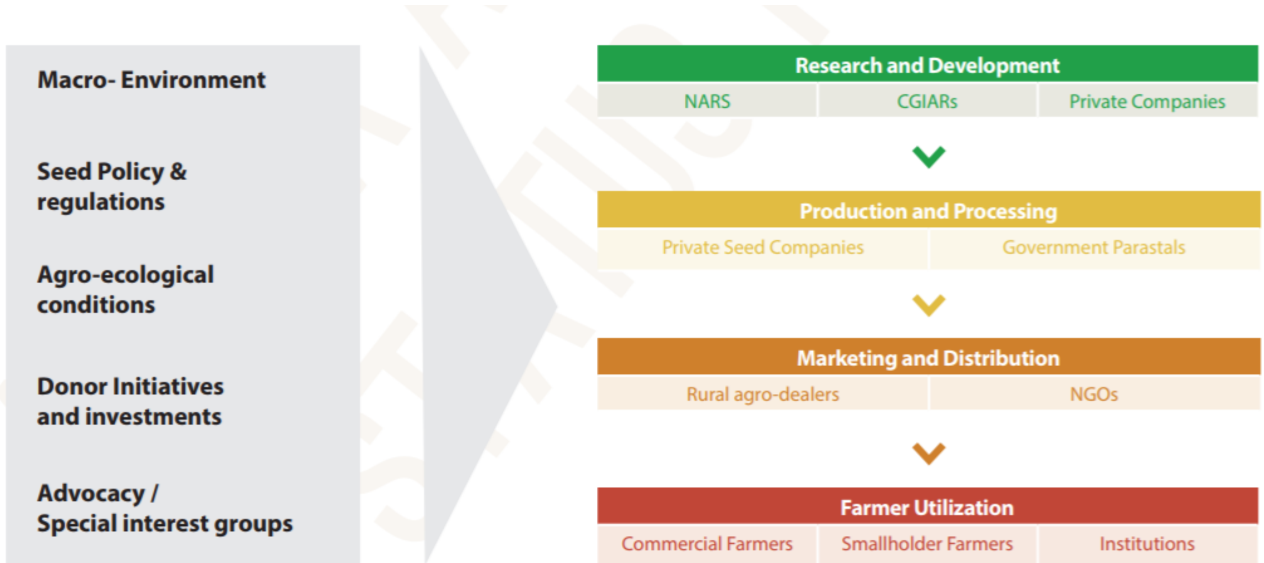

Figure 1. Stylized Structure of Formal Seed Systems in Sub-Saharan Africa (Adapted from AGRA)

In both classical and modern plant breeding techniques, comprehensive dimensions of technology convergence and a delivery model must come together for user-end access and adoption.[10] To develop improved crops, plant breeders need access to breeding materials from universities, public research institutions, and private companies. A series of breeding technologies must be pooled for primary product development and proof of concept validation. After field testing, technologies are then ready for regulatory validation, and final delivery by public and private institutions.[11] Successful upstream research, and downstream product development, shown in Figure 2, require a series of strategic partnerships over an interdependent delivery pipeline.

[10] (Vijayaraghavan, 2017)
[11] (Vijayaraghavan, 2017)

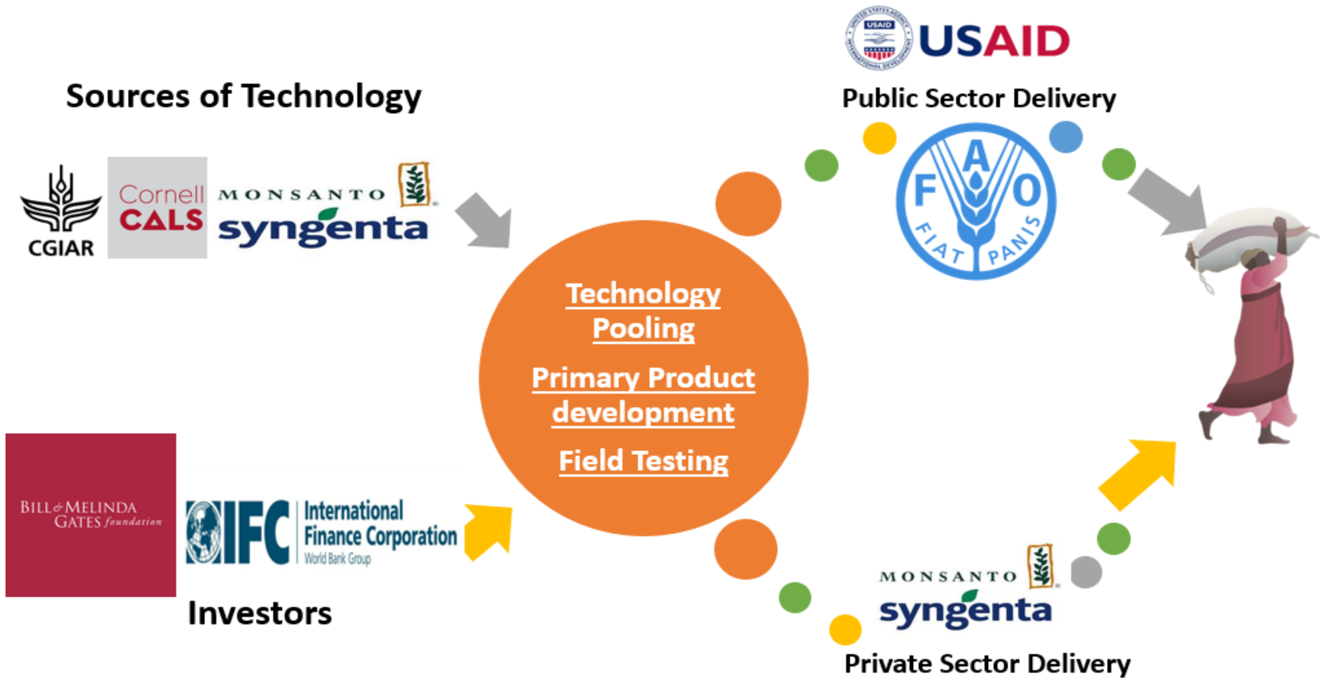

Figure 2: International dimensions of technology convergence and delivery model in Africa

(Vijayaraghavan, 2017)

Policy thrusts for innovation and technology transfer

Access to agricultural innovation and technology transfer cannot occur without the requisite political, social, economic, and legal policy landscapes. In addressing the needs of developing countries, widespread access to innovations must meet the requirements of affordability, acceptability and availability.[12] Krattiger and Mahoney have identified a six-prong strategy to

[12] (Krattiger, et al., 2007)

meet the three determinants for access to innovations. The six policy areas for facilitation access include:

- Development of R&D capacity and education by the public and private sector
- Development of a safe and effective regulatory system that covers agricultural inputs and outputs
- Development of manufacturing capability for seed production and value-added processing
- Development of an Intellectual Property system
- Development and expansion of national agricultural delivery systems, including an attractive, private sector domestic market for agricultural products and services
- Development of an international trade system for agricultural inputs and outputs

Figure 3 displays how these six areas and how they're interrelated. The policy areas should be viewed as components of a singular innovation ecosystem.

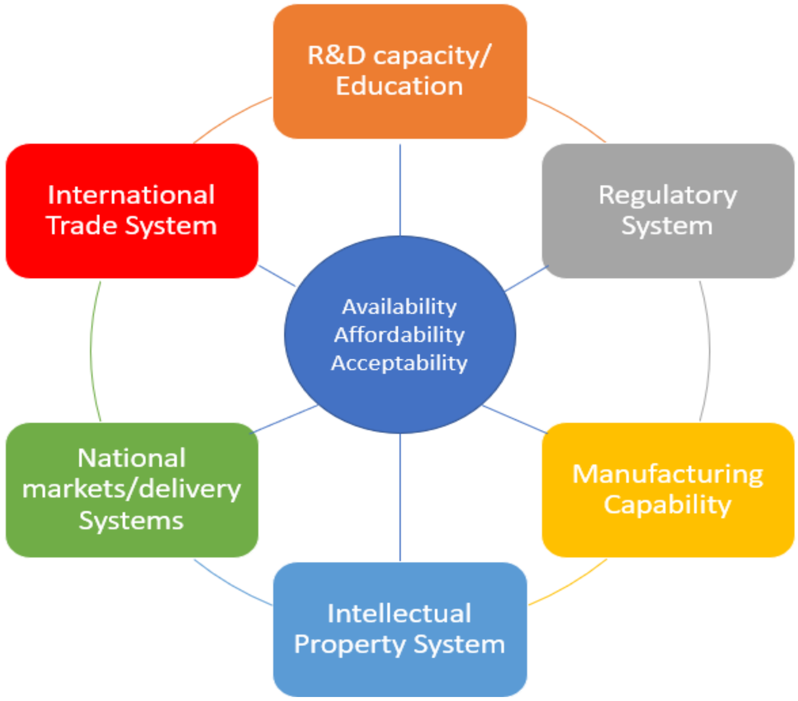

Figure 3: Six Policy Thrusts for Innovation & Technology Transfer (Krattiger, et al., 2007)

The aforementioned policy thrusts represent strategic policy barriers that must be overcome to ensure access to seeds. A brief comparison between Ethiopia and Kenya will demonstrate the role each plays in international dimensions of technology convergence for seed availability, affordability, and acceptability. The tables below provide a side-by-side comparison from data compiled by the Africa Seed Access Index.

MANUFACTURING CAPACITY		
	Ethiopia	Kenya
Number of active seed companies	In 2015, there were 60 registered entities in Ethiopia producing and/or marketing at least one of the focus crops.	The number of registered seed companies in Kenya has grown from less than 10 at the turn of the millennium to 112 in 2016.

Varieties released in the last 3 years	37 varieties: 12 for maize, 15 for wheat, 3 for teff, and 7 for sorghum	50 varieties: 35 maize varieties, 15 sorghum varieties, 10 bean varieties, but no cowpea varieties

Table 1 Seed Manufacturing Capacity (Adapted from TASAI)

The manufacturing capacity for seeds between the two countries is significant. Kenya has nearly double the number of active seed companies; it is evident that this gives them a significant advantage in production. Maize and sorghum are among the primary varieties in both countries. In the last 3 years, there were 35 maize varieties and 15 sorghum varieties that were released into the Kenyan market, whereas there were 12 maize varieties and 7 sorghum varieties that were released in the Ethiopian market.

NATIONAL MARKETS & DELIVERY SYSTEMS		
	Ethiopia	Kenya
Concentration of rural agro-dealer network	The DSM model has achieved significant growth in coverage from two woredas (districts) in 2011 to 100 districts with 650 agro-dealers in 2016 (this translates to one agro-dealer for 24,294 households).	The recently launched Seed Sector Platform KENYA lists over 5,240 agro-dealers in Kenya. This is 15% higher than the number in Kenya Plant Health Inspectorate Service (KEPHIS) records.
Availability of seed in small packages	Across the four focus crops, less than 1% of the certified seed sold in Ethiopia is sold in package sizes of 2 kg or less. The corresponding figures are	In 2015, 79% of the seed sold by the seed companies was packaged in bags weighing 2 kg or less. While this number is down from 89% in 2013, it still represents an excellent

	0.3% for maize and 0.6% for teff, while no wheat or sorghum seed is sold in package sizes of 2 kg or less.	rating. The figures for individual crops are as follows: 73% for maize, 96% for sorghum, 93% for beans and 100% for cowpeas

Table 2 Seed National Markets and Delivery Systems (Adapted from TASAI)

The development of the national markets and a seed delivery system are also critical seed access. In 2011, with support from the Ethiopian MoANR, ATA and the Integrated Seed Sector Development (ISSD) piloted the Direct Seed Marketing (DSM) model.[13] This effort brought the number of agro-dealers in Ethiopia up to 650. This number is quite low compared to Kenya's 5,240. Another barriers to seed access for small holder farmers is availability of seeds in small quantities, the Ethiopian seed system also lagged in this aspect with less than 1% of certified seeds being sold in 2kg or less. In Kenya, 79% of the seeds sold was packaged in bags weighing 2kg or less.

REGULATORY FRAMEWORK		
	Ethiopia	Kenya
Quality of seed regulations and enforcement	Seed companies rate their satisfaction with the quality of seed regulations and enforcement as good – 65% and 57%,	Seed companies rate their satisfaction with the quality of seed regulations and enforcement as good 65% in 2013 to 62% in 2015
Adequacy of seed inspectors	There are 32 public seed inspectors in Ethiopia. In addition,	KEPHIS employs

[13] (Cornell Univerisity, 2018)

	several private seed companies have their own seed inspectors, though they are not licensed by the government.	hundreds of staff, of whom 64 are involved in seed inspections.

Table 3 Seed Regulatory Framework (Adapted from TASAI)

For successful delivery of seeds, there must also be a strong regulatory body that protects farmers against inapt seed technologies. Efficient and effective regulatory plays a major role in ensuring quality. Seed companies' satisfaction rating are somewhat similar in Kenya and Ethiopia. The number of public seed inspectors in Kenya is 64, and 32 in Ethiopia.

INTERNATIONAL TRADE SYSTEM		
	Ethiopia	Kenya
Length of import/export process for seed	Only one seed company imported seed into Ethiopia in 2016. This company reported that it took more than three months to import seed. There were no exports of certified seed from Ethiopia	On average in 2015, it took 38 days to import seeds (down from 43 days in 2013) and 14 days to export seeds.

Table 4 International Seed Trade Systems (Adapted from TASAI)

When there are significant deficiencies in a national capacity to manufacture seeds, international trade systems become even more critical. The ability to import seeds also needs to be efficient. One company that imported seeds into Ethiopia reported that process took more than three months to import seeds into the country. On the other hand, it takes an average of 38 days to import seeds into Kenya. Ethiopia has no certified seeds exported so there is no data available on the time it takes export seeds, but it takes 14 days to export seeds from Kenya.

R&D, EDUCATION EXTENSION CAPACITY		
	Ethiopia	Kenya
Number of active breeders	74 for 15.6 million farming households	63 for 6 million farming households
Availability of extension services	there are approximately 18,015 agricultural extension workers in Ethiopia, of whom less than 1% (70) are from the private sector.	the ratio of public sector extension workers to farmers in Kenya is about 1:910. This is a slight improvement from the 2013 ratio of 1:1000

Table 5 Research, Development, Education, and Extension Capacity (Adapted from TASAI)

The capacity to do research in breeding and extension services are also important in driving access to improved varieties. There are about 4.7 breeders for every 1 million farming households in Ethiopia, whereas in Kenya there are about 10.5 for every 1 million households. The availability of extension is also a driver of seed access. Ethiopia has a much larger number of extension agents which nearly equates to one worker for every 592 farming households in Ethiopia whereas Kenya extension ratio is nearly 1:910.[14]

Across five of the six areas of policy drivers that influence seed access, Kenya bolsters a much stronger seed system. These policy areas affect one another, it is insufficient to simply focus on one area. For innovation in seed system to take place, efforts must be made in each of these areas

[14] (Cornell Univerisity, 2018)

simultaneously. While individual policy areas may require different levels of effort and priority, failure in any of these thrusts can act as barriers for innovation and improving access. Much effort has been placed in the aforementioned five areas of agricultural development. The sixth strategic prong is intellectual property, and it has largely been neglected as a tool for development and an enabler of innovation, and technology transfer in agricultural systems.

Intellectual Property

Intellectual property (IP) rights are rights to the product of the mind that can be afforded legal protection; that is, ideas and the way they are represented, whether a process, manufacture, an artistic representation, or a composition of matter.[15] Intellectual properties can be protected by means of copyrights, trademarks, patents, plant breeder's rights, and trade secrets.[16] For seed technology, patents might, for example, cover plant transformation methods, vector genes, or transgenic plants.[17] IP protection may be obtained under two regimes: plant breeder's rights, and in some jurisdictions, the regular patent system.[18] New plant varieties must meet the criteria of "novelty, distinctness, uniformity, and stability", the breeder may be granted a patent, or plant breeder's rights certificate, giving them the exclusionary rights over the invention for a limited period of time.[19]

[15] (Binenbaum, Nottenburg, Pardey, Wright, & Zambrano, 2000)
[16] (World Intellectual Property Organization, 2018)
[17] (Binenbaum, Nottenburg, Pardey, Wright, & Zambrano, 2000)
[18] (Binenbaum, Nottenburg, Pardey, Wright, & Zambrano, 2000)
[19] (Krattiger, Innovation and Intellectual Property Management, 2017)

Figure 4: Criteria for obtaining Plant Variety Protection (PVP) & Patents

IP rights spur innovation in many ways. For instance, IP rights provide temporary exclusionary rights, breeders have a monopoly for 20 years from the date of application filing. This period provides breeders with an opportunity to license and profit from their technologies.[20] Patents reward scientific progress by offering inventors rights in return for their inventiveness and research efforts.[21] This creates an incentive for the generation of new ideas, and continued investment in future breeding research.[22] IP rights also stimulate further advancement through the dissemination of new ideas by way of publication and licensing.[23] When patents are granted, the method invention must be disclosed to the public. In addition, plant breeder's rights have a research exemption that allows for breeders to further develop new varieties, and a farmer's exemption that allows farmers to save seeds for the sole purpose of replanting.[24]

[20] Ibid.
[21] (Merges & Duffy, 2013)
[22] (Binenbaum, Nottenburg, Pardey, Wright, & Zambrano, 2000)
[23] Ibid
[24] (Krattiger, et al., 2007)

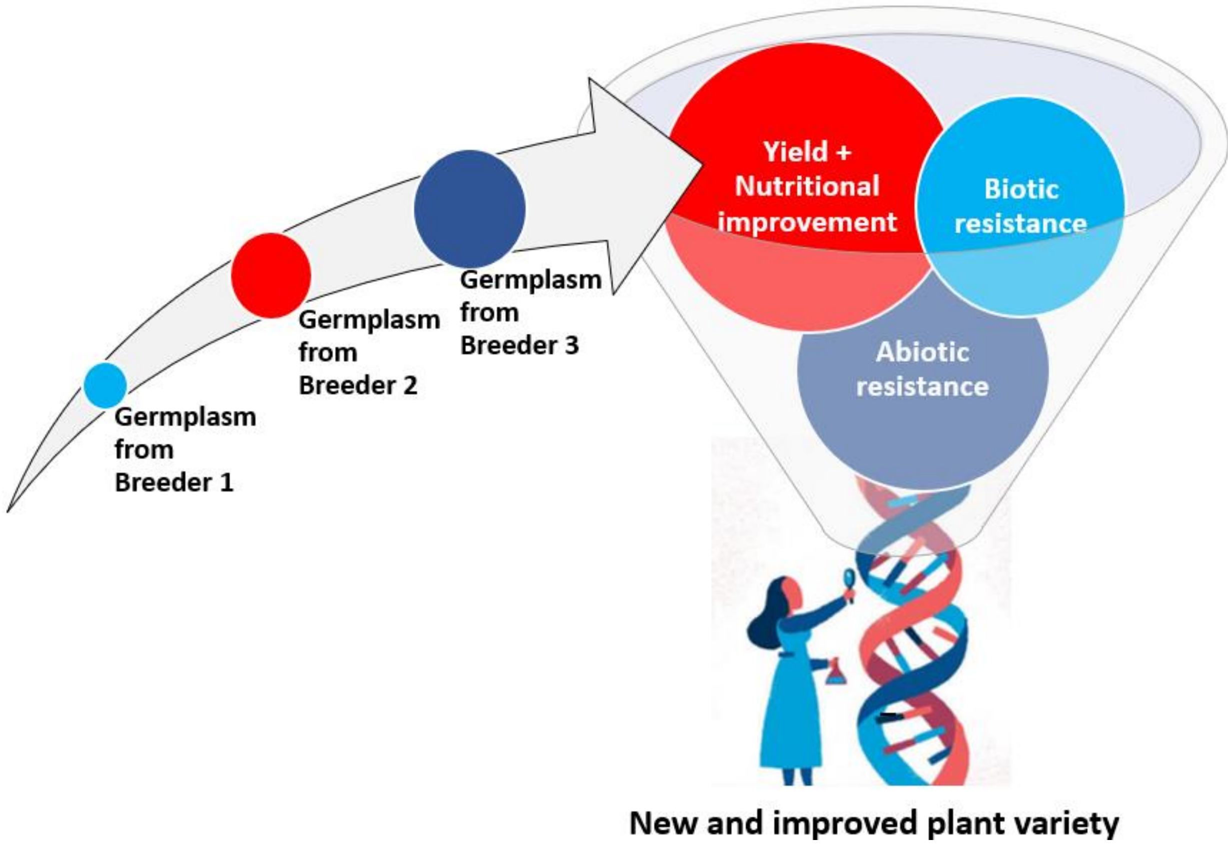

Figure 5: Technology pooling and collaboration for developing new and improved plant varieties

The transfer of technology from highly complex capital-intensive environments to low capital recipients[25], as shown in Figure 2, require exchanges of technology and know-how. IP rights allow the owners to exclude others from using, producing, selling, or importing their invention to the country in which the patent was granted[26], but also allow for the transfer of inventions and technologies. Developing seed technologies requires the successful pooling of resources between breeders; that is, multiple actors must agree to share knowledge and bio-property to bring new plants to the market. The need to exchange germplasm —living genetic resource such as plant tissue and know-how is critical for developing improved varieties. If a breeder is interested in

[25] (Wollongong, n.d.)
[26] (Krattiger, et al., 2007)

developing a variety with improved biotic resistance, they will need to license existing varieties that exhibit favorable traits from other breeders. IP rights grant the use and transfer of technologies that enable collaboration, down-stream development, and delivery through licensing.

Kenya has an older more established intellectual property regime established in with the enactment of the 1990 Kenya Industrial Property Act.[27] Ethiopia's intellectual property laws was passed in 1995 with the Inventions, Minor Inventions, and Industrial Designs proclamation.[28] Kenya has an more established intellectual property system enforced by the Kenya Industrial Property Institute.[29] The Ethiopian Intellectual Property Office is the national IP administration and has recently announced that it is establishing a separate court for IP cases.[30] Ethiopia is not a signatory of the WTO, TRIPS, and the UPOV; Kenya is a signatory of all three agreements.[31] These six policy areas used for analysis seed systems also affects other industries within agricultural systems. While the two countries are similar in many ways, the global innovation index ranks Kenya much higher than Ethiopia. Comparisons were made across institutions, human capital, infrastructure, market sophistication, creative outputs, knowledge and technology outputs, business sophistication. Kenya is ranked at 80th and Ethiopia at 110th out of 126 listed countries.[32]

[27] (Krattiger, History of Intellectual Property, 2017)
[28] (Ministry of Indistry, Trade, and Competitiveness, 2016)
[29] (2markato, 2012)
[30] (Getnet, 2017)
[31] (World Trade Organization, 2017)
[32] (Dutta, Lanvin, & Wunsch-Vincent, 2017)

CHAPTER 3

Policy Limitations and Considerations for Adoption

IP rights can be catalyst for innovation and investment; they allow for the transfer of scientific and industrial processes, inventions, and know-how.[33] Nonetheless, an efficient IP system is only one of six thrusts that drive innovation and access to technology. IP cannot substitute the development of national critical infrastructure needed for an efficient agricultural delivery system. Lack of roads, finance, markets, education, and R&D capacity can impede innovation and technology transfer. An efficient IP system also cannot overcome market failures that create fragmented and incomplete pipelines for product development and delivery shown in Figure 5. Like the pharmaceutical industry, the cost of developing solutions for a small number of groups with limited resources makes private breeding companies averse to these kinds of investments. The mirror image of orphan drug in pharmaceuticals is an orphan crops in agriculture; a crop that remains commercially underdeveloped owing to limited potential for profitability.[34]

[33] (Cahoon, 2017)
[34] (Krattiger, Innovation and Intellectual Property Management, 2017)

Figure 6: Development and delivery pipelines, Profitable vs Orphan crops (Krattiger, Innovation and Intellectual Property Management, 2017)

Public agricultural research institutions such as National Agricultural Research Systems (NARS), Consultative Group for International Agricultural Research Centers (CGIARs), and universities, of often lack the operational capacity and expertise for down-stream development. That is the capacity to manufacture, distribute, market, sell, product development and other capacities associated with business operations. Profitable seeds developed by the private sector companies have fully integrated down-stream delivery pipeline, whereas seed technologies in public research institutions are very fragmented as shown in Figure 1. This has limited the number of publicly developed seeds from reaching African farmers; farmer-saved seed accounts for approximately 80% of planted seeds, compared to a worldwide average of 35%.[35]

When developing an IP system, policy-makers must also be careful to balance rights granted by the patent with the advances brought by the scientific advancement. Excessive monopolies and

[35] (Alliance for a Green Revolution in Africa, 2017)

competing claims of ownership over inventions in a technology could prevent others from using it, frustrating what could have been a socially desirable outcome. This phenomenon is referred to as the tragedy of the "anti-commons"[36]; a term coined by Michael A. Hellen. To avoid this type of gridlock, the plant breeding industry needs to apply an open innovation model similar to the information technology industry. There are hundreds of patents in one cell phone, from the software, to the battery chemistry, to the compound that is used for the screen. There is seamless integrating of intellectual property that is attained through open collaboration of software and cross-licensing. Cross licensing and the open innovation model can be applied in plant breeding. This requires the transfer and share of germplasm and bio-property between public, private, and informal actors. This process can be facilitated through materials transfer agreements and licenses that can define use and ownership and rights coming from such collaborative opportunities.

In other cases, a barrier to technology adoption is end-user acceptability. Even when technologies can be delivered, consumers may be unwilling to adopt them. A weak regulatory framework can lead to inapt technologies reaching farmers. Opposition to accepting new technologies may also be cultural, or perceived risks in the case of transgenic crops. Policy-makers should not force technologies on communities resistant to new innovations. In this case, it is the responsibility of policy-makers to use empirical evidence to distinguish between hazards and risks, educate consumers, and let the farmer choose technologies to adopt.[37]

Successful technology transfer of seeds is that the end product be acceptable to famers. If a product or service is developed for farmers, it is the responsibility of manufacturers and service-providers to ensure that their technology meets the farmer's needs. Burden should not be placed

[36] (Cahoon, 2017)
[37] (Juma, 2016)

on the farmer to adopt inapt technologies, or ones that have been de-risked to the farmers' satisfaction. Everett Roger's proposes five factors that influence the likelihood of a technology being adopted. The first, is relative advantage, how much better it works relative to existing substitutes. The second is compatibility, this is how well an innovation is compatible with the adopters. The third is complexity, technologies that are difficult to operate and more complex are less likely to be adopted. The fourth is triability, farmers are more likely to adopt technologies can try. And the final factor is observability, there must be some observable change from using this technology if a farmer will adopt it. Both factors for access, and adoption must be met successful adoption of seeds.

Krattiger and Roger's models only explains initial adoption, technologies also need to be sustained. To improve the likelihood of sustained adoption, technologies must have complimentary assets and network effects. Complimentary assets are factors that enable or enhance technologies, in the case of seeds they can be pesticides, insecticides, fertilizers, or other inputs. Network effects are the positive effects that occur as a result of a large number of users using a particular technology. Network effects in seed systems are experienced when a large number of farmers and actors across a value-chain are developed around a specific crop. Innovation in seed development also requires that seeds not be viewed as stand-alone technologies. Seeds require complimentary assets to reach their full yield; they are more likely to be adopted if they are delivered with the needed supporting technologies. Complimentary assets with seeds such as inputs may improve yield, or reduce crops loss, increasing the expected return on investment a farmer makes when choosing to adopt new varieties. Plant breeding requires extensive field trials and data collection on multiple generations of plant varieties. Experiment stations are used for field trials under controlled conditions and seeds are often not acclimatized and localized to farmer's fields in Africa. The environmental heterogeneity of African farmers doesn't mean it is impossible to deploy seeds for all of them but that different complimentary assets will be required for each type of farmers and local agricultural system. This localization frequently used by companies such as Google, is the process of customizing technologies and services to meet the needs of consumers across different regions. Rather than developing seeds for a large number of farmers, a geographically focused investment of seeds and complimentary assets may result more successful adoption of improved varieties.

Participatory approaches in plant breeding offer an innovative solution to address many of the barriers to seed development and delivery. African farmers are constant pressure to innovate; they're not only innovating in terms of component technologies but also terms of farming systems.[38] Farmer's face constantly evolving set of challenges in their fields, this requires dynamic seed development strategies. Public research institutions can leverage farmer knowledge to create iterative breeding programs that will improve the likelihood seed access and adoption. The Corning Corporation develops their technology by incorporating their client needs and ideas into their product development process. Applying these principles in public research institutions can create a synergistic relationship that overcome the public sector's underdeveloped product development process. Directly testing varieties on farmer's fields will allow plant breeders to evaluate performance of their technologies when it's in the hands of farmers. This valuable feedback can help farmer adapt to new varieties. Participatory breeding models also meet many of the criteria farmers consider when choosing to adopt new technologies. This inclusive model allows farmer to try new seeds, evaluate their relative advantage, their observability, and compatibility.

[38] (Roling, 2012)

A participatory approach can also provide early detection of plant acclimatization to local conditions. This approach lacks scientific rigor traditionally found in research institutions by sacrificing accuracy for precision. Reliability can be minimized by leveraging information technology and public extension services. Recent advances in data collection and analysis through digital platforms allow for low cost trials of new varieties in farmer's fields. This allows plant breeder to monitor and evaluate their technology in the field while it's in the hands of famers rather than after the investments have been made in developing the seeds.
Extension services can also be leveraged to support this process. The evolving role of agricultural extension agents can evolve to include competencies such monitoring the success of introducing new varieties, technology adoption support, and identifying complimentary assets required to ensure sustained adoption. Extension services should also include supporting networks of value chains actors around seed technologies. This service will give farmers market much needed market support and incentivize adoption. Farmers work and live in market systems; their crops must be marketable. Engaging value chain actors such as brokers, marketers, manufacturers, and consumers to invest in creating foods will add value to for the farmer as well the agricultural system.

Institutional Reform in Public Research Institutions

Not only does innovation in seed systems require changes in policy and practice but it also requires institutional reform. Institutional capacity for innovation is dependent on the free-flow of new ideas, and experimentation. Innovation demands that institutions try new things, even at the expense of divesting from existing practices. Institutional knowledge and infrastructure built around the first "green revolution" will not be the same ones needed to drive the next revolution in agricultural systems. Institutional funding cycles and focus must be geared towards new and disruptive innovations rather than sustaining existing technologies. Sustaining innovation only provides incremental improvements and return on investment whereas disruptive ones resulted in the first "green revolution". A recent report analyzed agricultural research productivity on corn, soy, wheat, and cotton research. There is a tremendous amount of research and development for biological efficiency because these crops have a very high commercial value. The study concluded that research productivity for these crops has fallen sharply for agricultural yield; yield growth has been relatively stable or even declining while the effective research that has driven this yield has risen tremendously.[39]

Crop	— Effective research — Factor increase	Average growth	Research Productivity Factor decrease	Average growth
Research on seed efficiency only				
Corn	23.0	7.8%	52.2	-9.9%
Soybeans	23.4	7.9%	18.7	-7.3%
Cotton	10.6	5.9%	3.8	-3.4%
Wheat	6.1	4.5%	11.7	-6.1%
Research includes crop protection				
Corn	5.3	4.2%	12.0	-6.2%
Soybeans	7.3	5.0%	5.8	-4.4%
Cotton	1.7	1.3%	0.6	+1.3%
Wheat	2.0	1.7%	3.8	-3.3%
Agriculture				
U.S. research, 1970–2008	1.9	1.8%	3.9	-3.7%
Global research, 1980–2010	1.6	1.6%	5.2	-5.5%

Note: In the first panel of results, the research input is based on R&D expenditures for seed efficiency only. The second panel additionally includes research on crop protection. R&D expenditures are deflated by a measure of the nominal wage for high-skilled workers. See footnote 14 and the online data appendix for more details.

Table 6, Research Productivity in Agriculture, 1969-2009 (Adapted from Bloom et al, 2017)

[39] (Bloom, Jones, Van Reenen, & Webb, 2018)

Table 6 displays research input based on research and development expenditures for seed efficiency only between 1969 to 2009, this includes hybridization and genetic engineering breeding directed at increasing yields, improving insect resistance, herbicide tolerance, and efficiency of nutrient uptake, etc…[40] There is a 9.9% research productivity loss in corn, 7.3% loss in soybeans, 3.4% loss in cotton, and 6.1% loss in wheat.

Support and incentive for public breeders should be in place for disruptive innovation that promise returns by factors rather than incremental improvements. Agricultural research institutions must encourage breeders to take bold risks when developing new varieties. There needs to be funding for new crops and new value chains that farmers may find valuable. Disruptive innovation requires that investment be made in new varieties that will displace existing ones by offering new and improved substitutes.

Conclusion

Norman Borlaug, widely considered the father of the "green revolution" has stated that while "[p]rivate industry has invested billions of dollars in research to make astonishing new discoveries and products, relatively few of the new crops developed by private industry are reaching smallholder farmers in the developing world". Both private and public institutions harbor a wealth of cutting-edge biotechnology, and yet much of this is inaccessible to the people who need it most. Actively licensing these technologies from public and private institutions using IP is a means of extracting both economic and social value from these assets.

[40] (Bloom, Jones, Van Reenen, & Webb, 2018)

Intellectual assets and bio-property held in these institutions are a means of food security. Advancement in improved seeds can include higher yields, nutritional improvements, reduced content of food allergens, sweetness, resistance to pests, disease, and droughts.[41] This new generation of advanced seeds can be force multipliers for agricultural productivity, but only if they are affordable, acceptable, and available to farmers. Breeding has, for too long, focused on yield. Plant breeders have the potential to bring more value to farmers by breeding crops that taste better, have a longer shelf-life, and even ones that have a more attractive hue.
Developing the foundations of a manufacturing base, national and international markets, research and development capacity, and a regulatory framework are critical for public access to agricultural innovations. While IP is not the most important factor, policy-makers need to recognize that it is a powerful tool for technology transfer and innovation. Seeds, like most complex technologies, are comprised of multiple inventions that are held together by IP. Establishing dynamic IP policies in private, public, and international breeding institutions is a step towards democratizing access to technologies and improving agricultural systems in Africa.
In addition to policy aspects, innovation in seed systems for improved access and adoption requires intervention on across multiple stages of seed development and delivery. It requires new practices at the delivery stages with breeders and institutions. It requires new perspectives of farmers as well approaches to meet their needs. Most of all innovating in seed systems requires the understanding that there is constant evolution in markets, environments, and systems farmers operate in. When developing crops for farmers, consideration for present and future conditions must be taken into account.

[41] (Juma, 2016)

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